Making the State of the Art the State of the Practice:
Modeling Tools for Road Pricing

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Presentation Outline

■ **General issues:**

1. Classification of pricing forms
2. Overview of modeling approaches

■ **Major breakthrough directions:**

3. Reliability
4. Heterogeneity of users in choice context
5. Heterogeneity of users in traffic simulation
6. Advanced time-of-day / peak spreading technique
7. Toll road as travel choice

■ **Conclusions**

1. Classification of Pricing Forms

Pricing Characteristics

- Facility
- Vehicle / traveler
- Unit of travel
- Collection

Pricing Characteristics

- **Facility** →
- Vehicle / traveler
- Unit of travel
- Collection

- Individual
- Area / cordon
- Sub-network (inter-city)
- Entire network

Pricing Characteristics

- Facility
- Vehicle / traveler ⟶
- Unit of travel
- Collection

- Flat
- Type (car, truck, CV)
- Auto occupancy
- Truck weight / axles / PCE
- Emission / fuel
- Residence
- Chains

Pricing Characteristics

- Facility
- Vehicle / traveler
- **Unit of travel** →
- Collection

- Flat per trip
- By TOD period
- By area
- Entry-exit
- Distance-based
- Time-based
- Congestion-based
- Daily / bulk discount

Pricing Characteristics

- Facility
- Vehicle / traveler
- Unit of travel
- Collection ⟶
  - Manual
  - Pass
  - Vehicle equipment
  - Automatic

2. Overview of Modeling Approaches

Wide Range of Techniques

- **Simplified sketch planning:**
  - ☑ *Short-term / Established facility*
  - Spreadsheet based on elasticity
  - Sample enumeration
- **"Real" models:**
  - ☑ *Long-term / New facility*
  - Regional model
 - Corridor-specific model

Focus on Regional Models

- **Network simulation (Route choice):**
  - Static UE assignment
  - Dynamic Traffic Assignment / Micro-simulation
- **Demand models (Mode / destination / TOD choices):**
  - Conventional trip-based 4-step
 - Advanced activity-based tour-based

Static Traffic Assignment

- Route choice only
- Vehicle type, occupancy, VOT, payment type, leads to multi-class w/full trip tables
- Cannot handle non-link and non-trip forms (entry-exit, daily)
- Cannot incorporate reliability / time variability
- Simplified toll-collection delays

- Simplicity
- Large networks
- VDF for distance time & congestion-based tolls

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Expert Forum on Road Pricing, USDOT,
November 14-15, 2005, Alexandria, VA
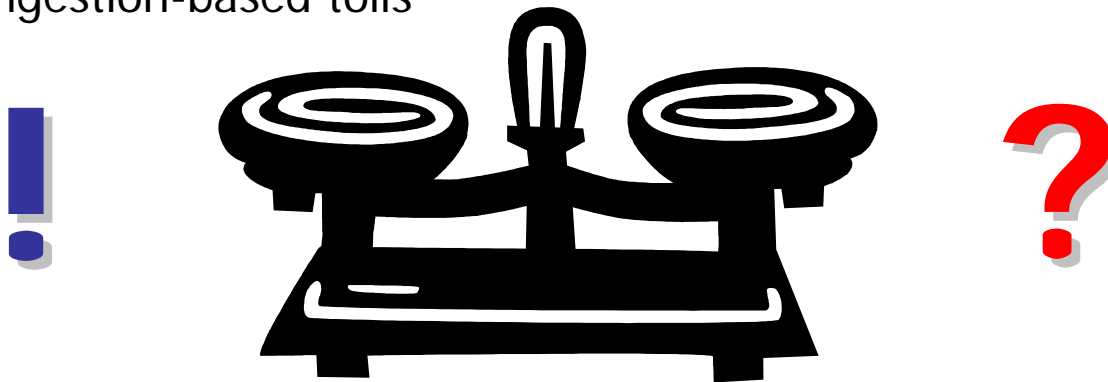
DTAssignment / MCSM

- Entire-route (non-link) pricing
- Linkage across TOD slices
- Queues / realistic delays
- Individual vehicle types
- Reliability / time variability

  - Route choice only
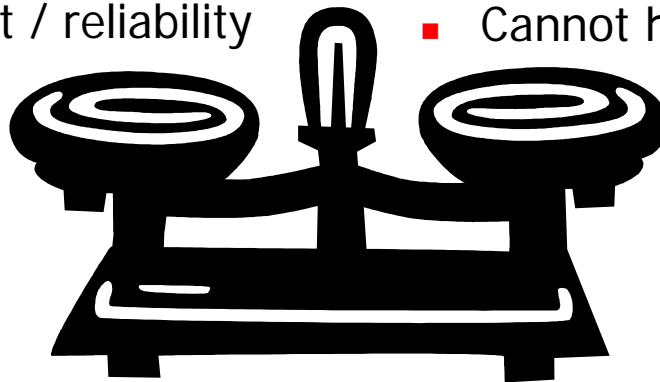 - Small & medium networks
  - Cannot handle daily pricing
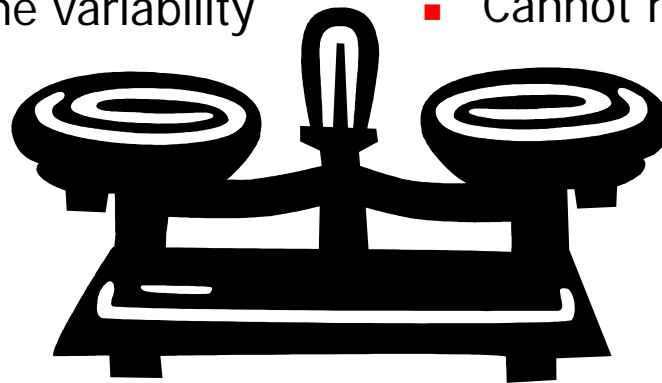
4-Step Trip-Based Model

- Simplicity
- Mode & trip distribution
- OD time & cost / reliability

- Limited segmentation
- Inconsistent TOD
- Inconsistent mode choice
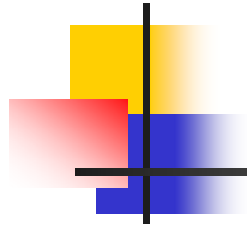- Car occupancy as mode
- Cannot handle daily pricing

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Activity-Based Tour-Based Model

- Consistent mode choice
- Consistent TOD & daily schedule
- Unlimited segmentation by VOT
- Vehicle type & occupancy as intra-household choices
- Payment type as individual choice

- Complexity
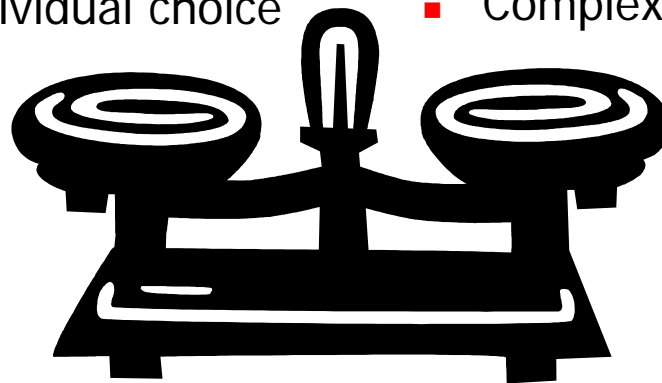
Breakthrough Directions

- Relevant and applicable in different modeling frameworks

- Theoretically substantiated and practically estimated & tested

- Based on conventional data sources

- Can be applied TODAY

3. Reliability

# Willingness to Pay

- **Value of Time (VOT)**
  - Lost participation in activities
  - Disutility of travel
- **Value of Reliability (VOR)**
  - Non-recurrent congestion
  - Accidents / Weather / Road works
- **Other Values:**
  - Safety
  - Information

Quantification of Reliability

- Alternative-specific constants (Indirect) :
    - Rail bias
    - Toll road bias
- Distance / time based terms (Indirect) :
    - Rail distance term
    - Toll-road distance/time/time-savings term
- Deviation from average travel time (Direct) :
    - Time distribution-based statistics
    - Schedule adherence indices for transit
    - Transit wait time curves
- Probability of significant delay (Direct) :
    - SP estimation
    - Function of V/C in application

VOR, Small et al, 2005, SR-91
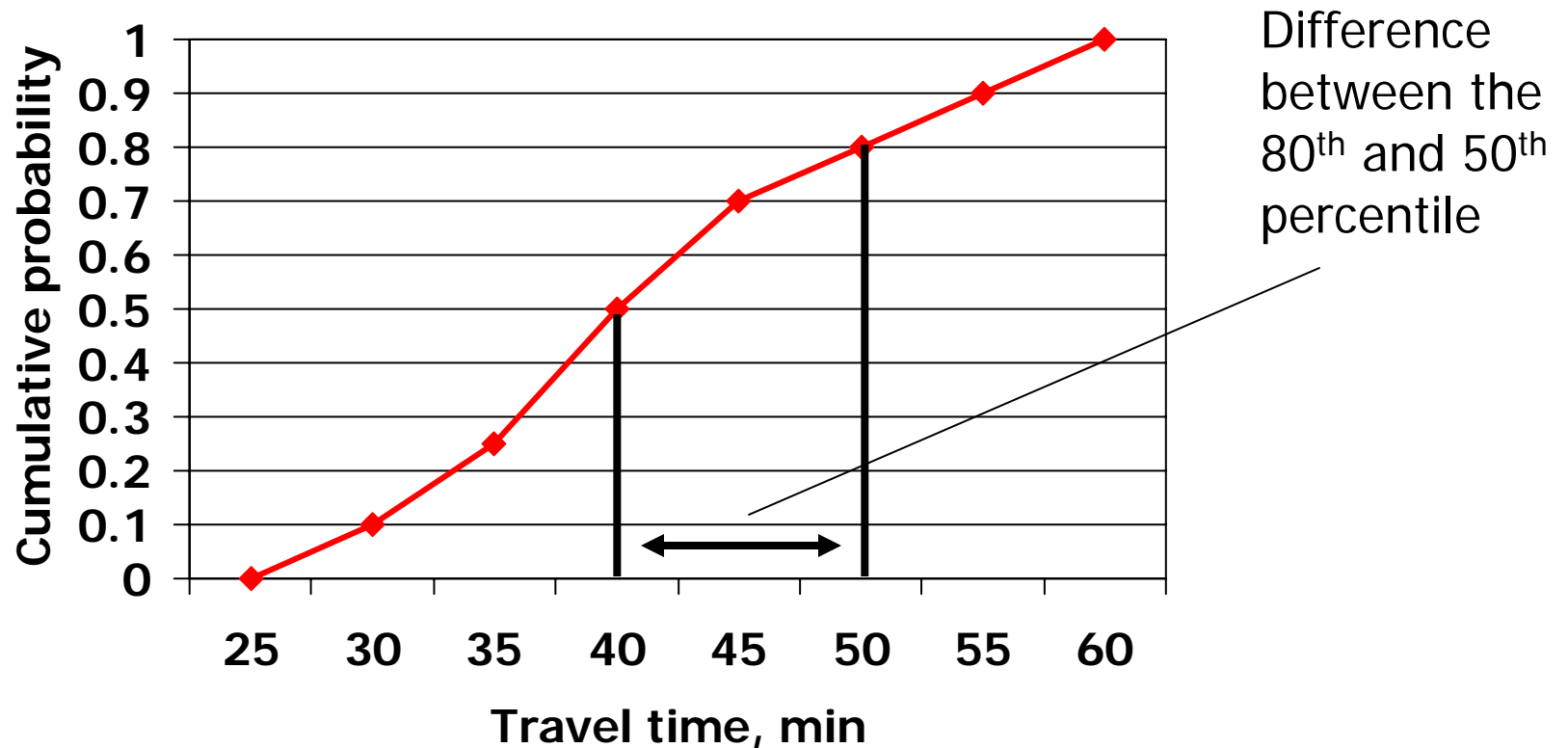
VOR, Small et al, 2005, SR-91

- Being late is more onerous than being early; thus 80th-50th is better than STD
- Distribution of travel times is assumed known to travelers based on their experience
- VOR is roughly equal to VOT
- Reliability accounts for 1/3 of the attraction of express lanes

VOR Illustration

Percentile	Road 1	Road 2	Preference
10	41 min	29 min	
20	42 min	30 min	
30	43 min	35 min	
40	44 min	39 min	
50	45 min	40 min	
60	46 min	41 min	
70	47 min	45 min	
80	48 min	50 min	
90	49 min	51 min	
100	50 min	52 min	

VOR Illustration

Percentile	Road 1	Road 2	Preference
10	41 min	29 min	
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VOR Illustration

Percentile	Road 1	Road 2	Preference
10	41 min	29 min	
20	42 min	30 min	
30	43 min	35 min	
40	44 min	39 min	
50	45 min	40 min	2nd road
60	46 min	41 min	
70	47 min	45 min	
80	48 min	50 min	1st road
90	49 min	51 min	
100	50 min	52 min	

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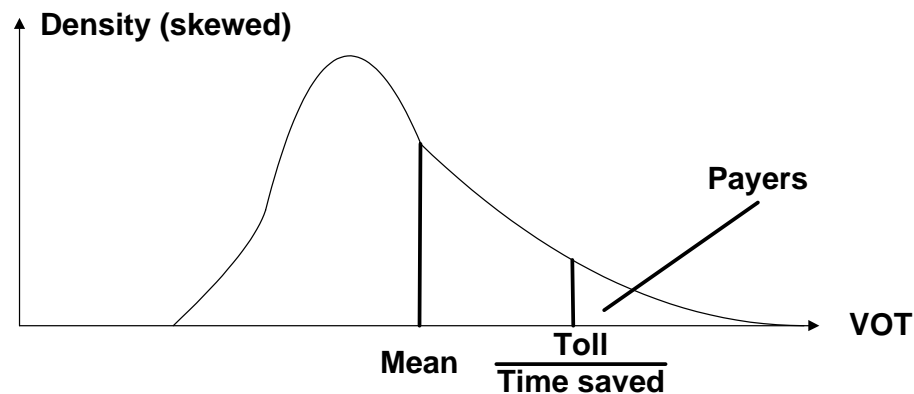# 4. Heterogeneity of Users in Choice Context

VOT Distribution
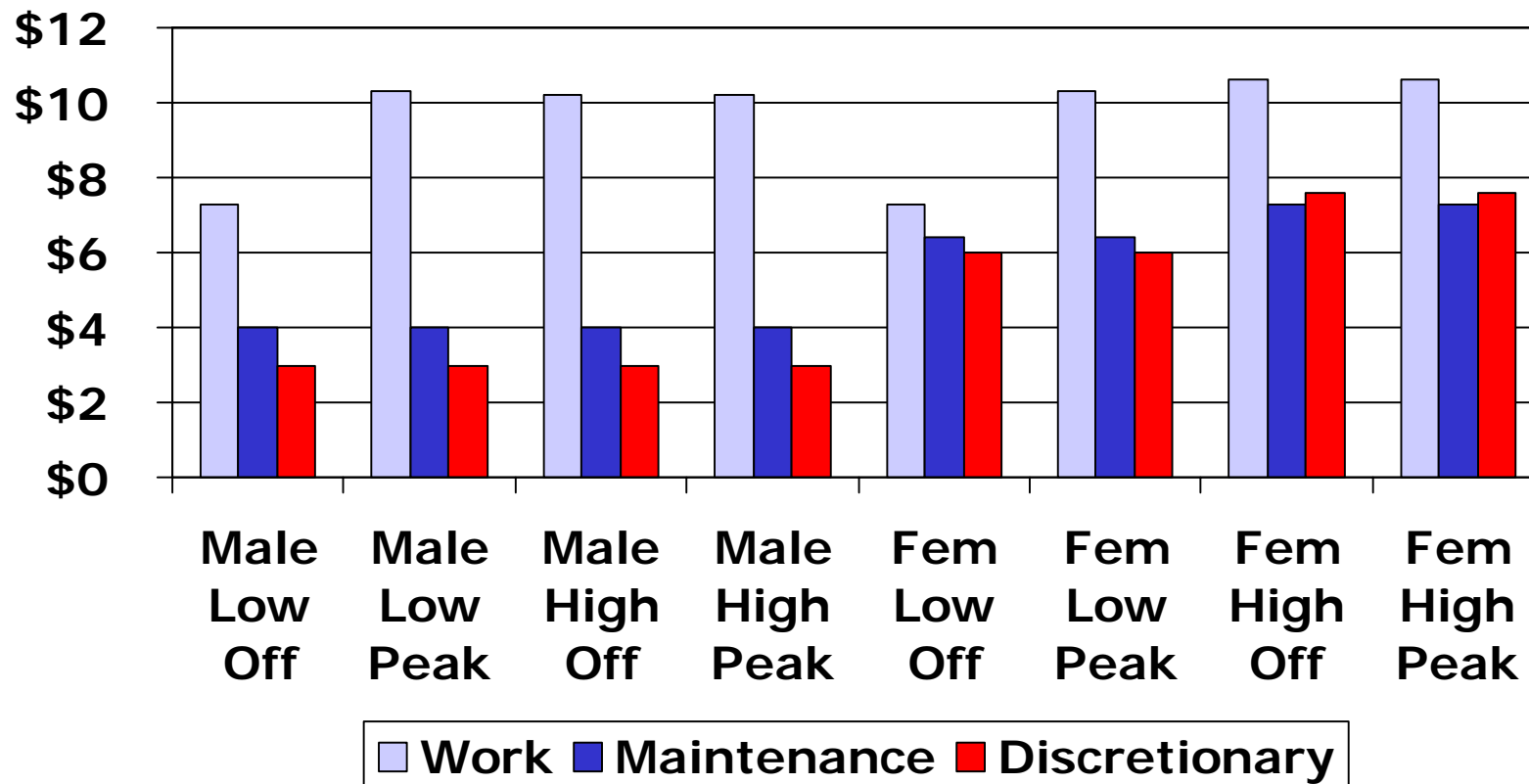# Hensher & Goodwin, 2003
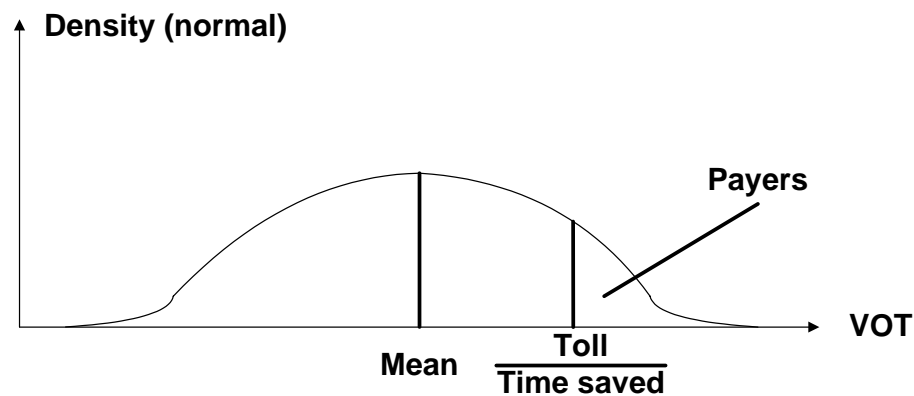
Density (normal)

Payers

VOT

Mean

$$\frac{Toll}{Time\ saved}$$

Density (skewed)

Payers

VOT

Mean

$$\frac{Toll}{Time\ saved}$$

Expert Forum on Road Pricing, USDOT,
November 14-15, 2005, Alexandria, VA

26

VOT – NY Model

Bar chart showing value of time (VOT) by trip purpose: Work ≈ $15, School ≈ $6, Univ ≈ $11, Maint ≈ $12, Discr ≈ $10, At work ≈ $40.

VOT – Montreal Model

Chart showing Value of Time (VOT) in dollars for eight categories: Male Low Off, Male Low Peak, Male High Off, Male High Peak, Fem Low Off, Fem Low Peak, Fem High Off, Fem High Peak. Legend: Work, Maintenance, Discretionary.
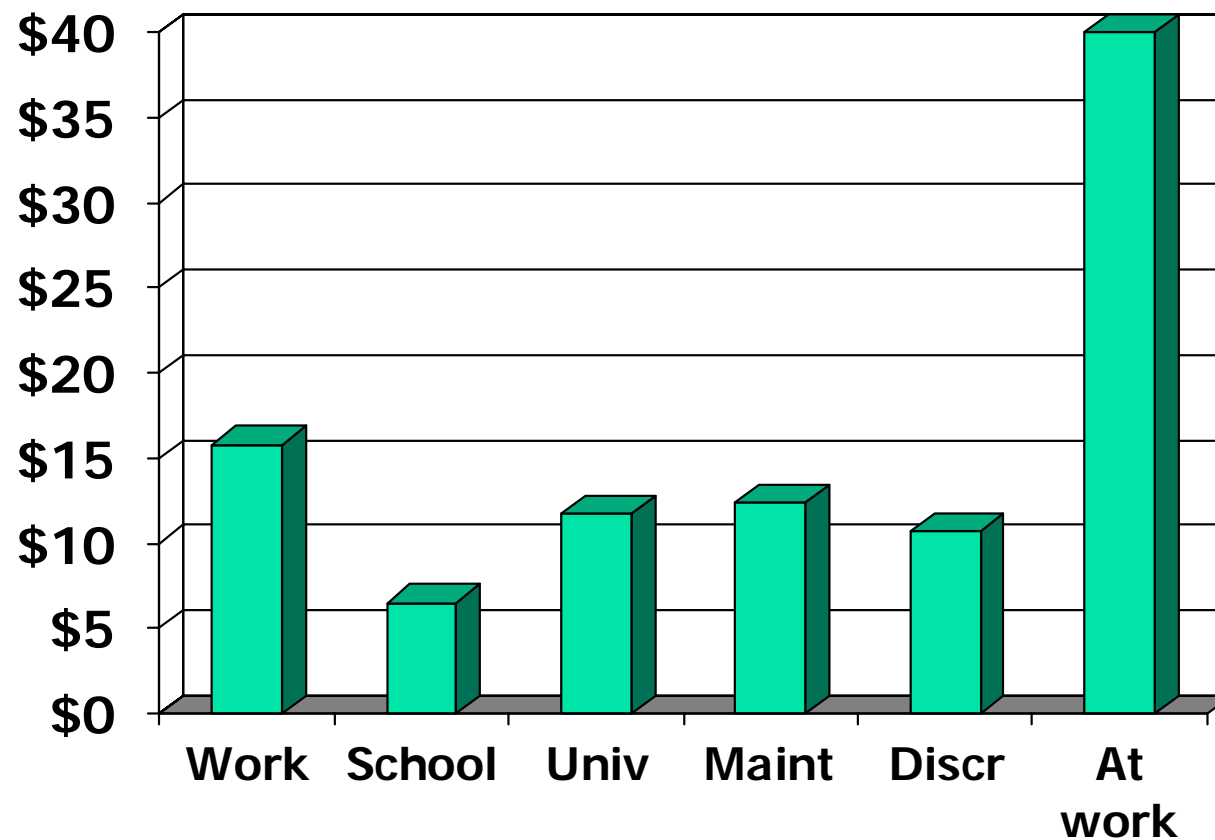
Possible Segmentation

- 3-4 income groups
- 3-4 travel purposes
- 2 genders

✗

- 2-3 person types
- 2-3 TOD periods
- 2-3 vehicle occupancy classes

200-300 segments / trip tables

Probabilistic Approach

- All possible segments cannot be handled
- Significant situational variability (intra-segment and intra-person):
  - Trip to airport
  - In a hurry for business meeting
  - Driving home because child is sick
  - Late for a music show
  - Flexible vs. fixed work hours

Random Coefficients Logit Small et al, 2005

$$U_i = \alpha_i + \beta \times TIME_i + \gamma \times COST_i + \varepsilon_i$$

$$\alpha_i = \overline{\alpha}_i + \varphi_i \times FEMALE + \eta_i \times YOUNG + \xi_i$$

$$\beta = \overline{\beta} + \lambda \times INCOME + \nu \times DISTANCE + \zeta$$

$$\gamma = \overline{\gamma} + \delta \times INCOME + \theta \times DISTANCE + \vartheta$$

Random Coefficients Logit Small et al, 2005

☑ Simultaneous and consistent estimation of:

 ☑ Observed heterogeneity - segmentation

 ☑ Unobserved heterogeneity – random terms

☑ Software for estimation is available

☑ Easily applied in micro-simulation by direct generation of random utilities

⧖ Requires numerical integration of probability for aggregate models

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5. Heterogeneity of Users in Traffic Simulation

Bi-Criterion Route Choice

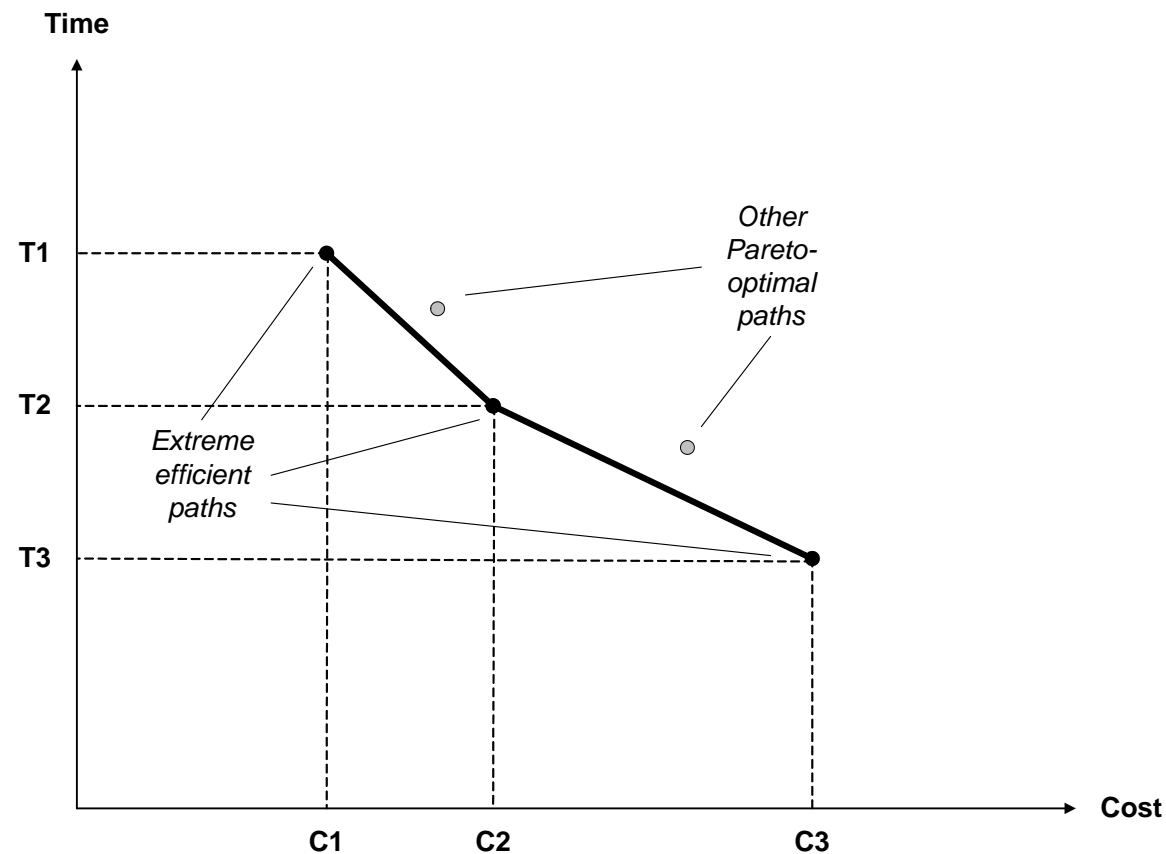
O $1 $1   D
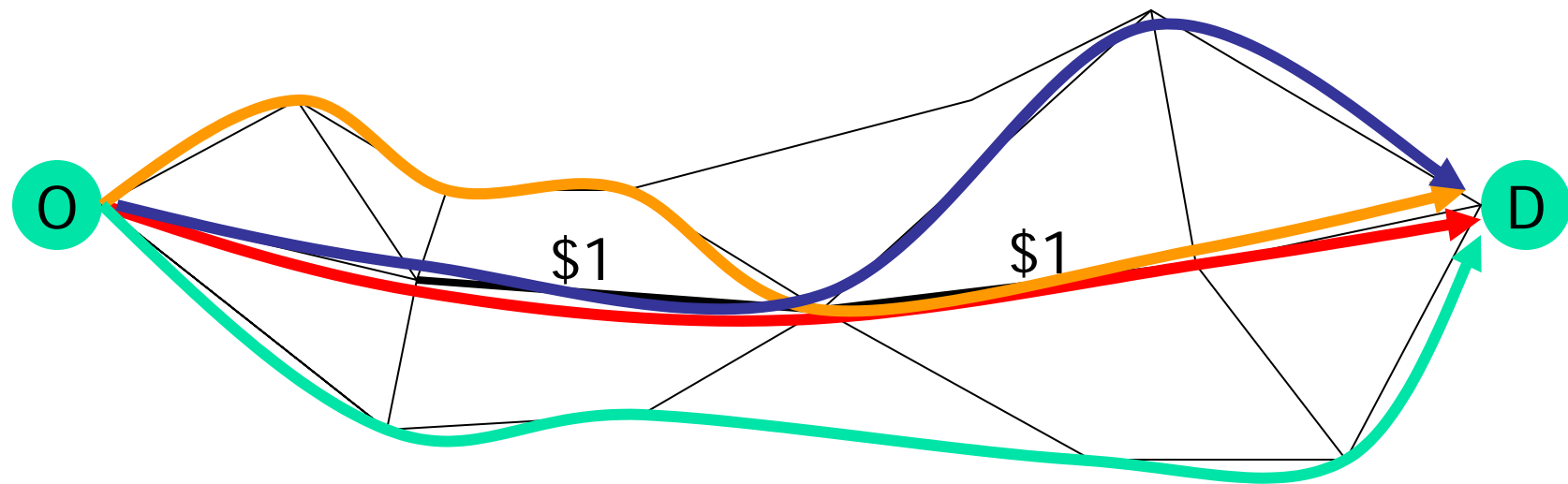
30 min
$2

35 min
$1

40 min
$1

45 min
$0

Extreme Efficient Paths, Mahmassani et al, 2004

Time

- T1
- T2
- T3

Other Pareto-optimal paths

Extreme efficient paths

Cost

- C1
- C2
- C3

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6. Advanced TOD Choice / Peak Spreading Technique

Entire-Tour Effects

Work tour to schedule

5   23

Entire-Tour Effects
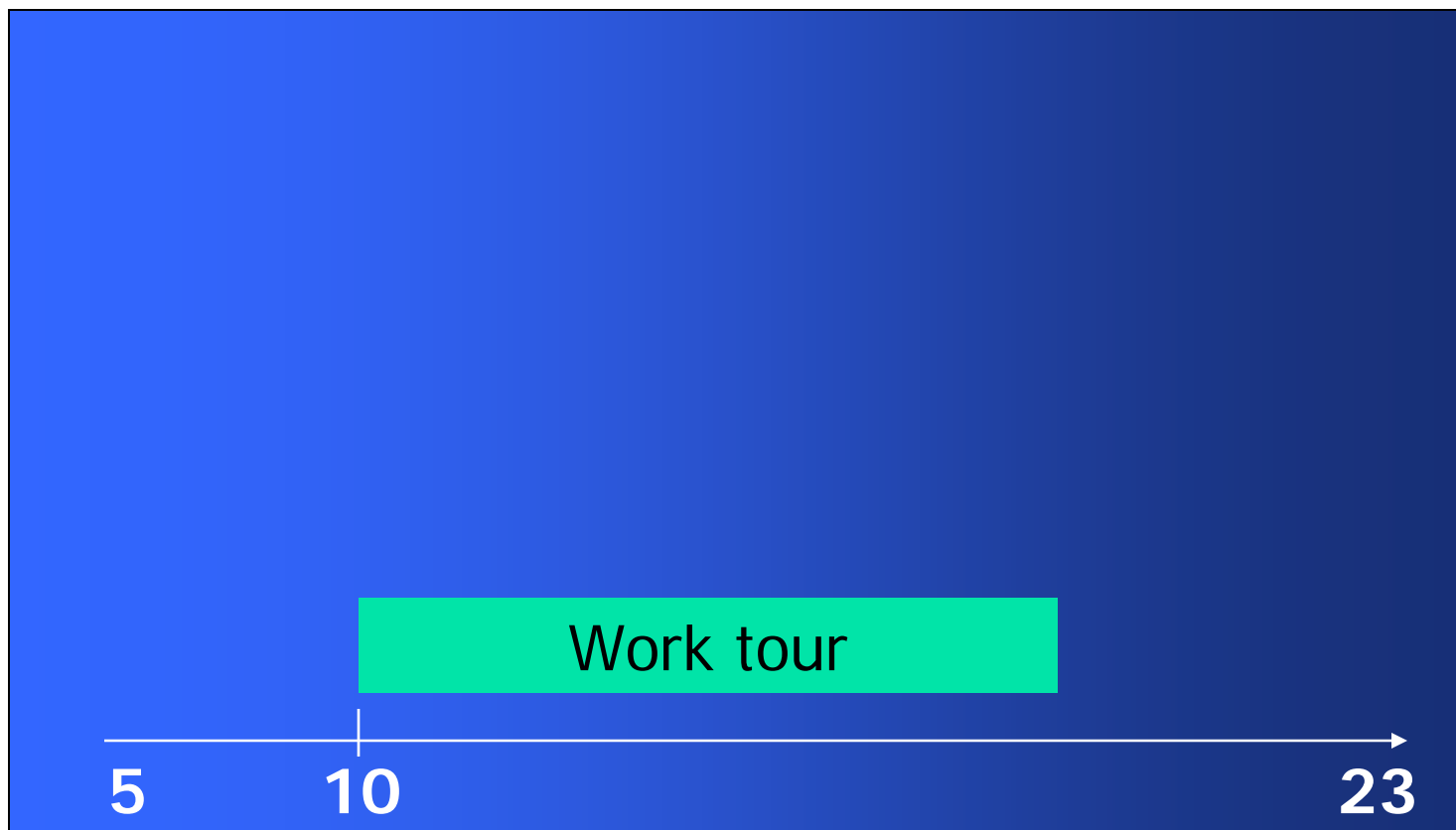
Work tour to schedule

Considerations for departure time:
• Office hours (7-10)
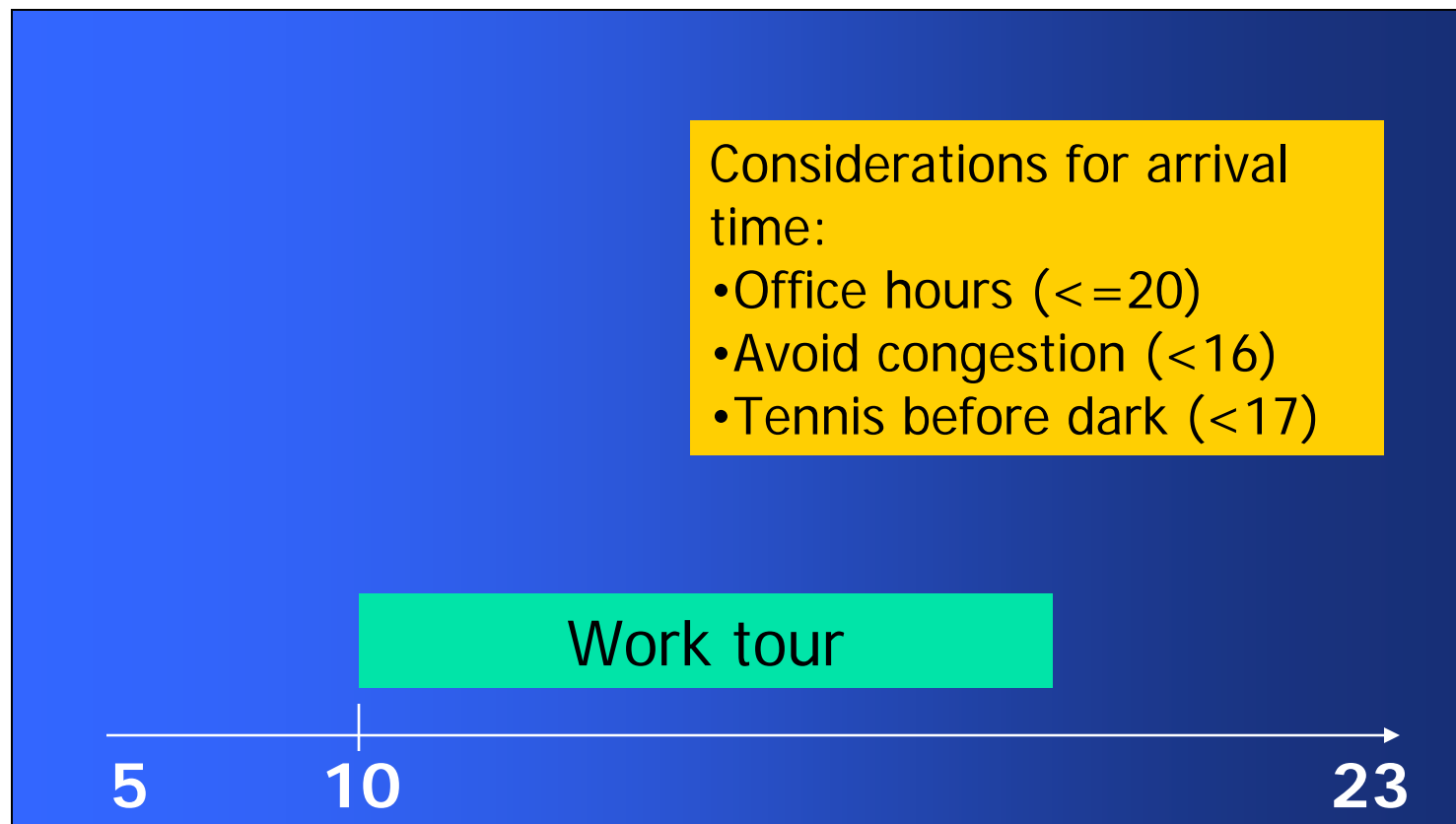• Avoid congestion (10+)
• Give ride to child (7)

5   23

Entire-Tour Effects

Work tour

5   10   23

Entire-Tour Effects

Considerations for arrival time:
- Office hours (<=20)
- Avoid congestion (<16)
- Tennis before dark (<17)

Work tour

5   10   23

Entire-Tour Effects

Considerations for duration:
- 8 work hours
- Finish presentation on Pricing

Work tour

5   10   15   23

Entire-Tour Effects
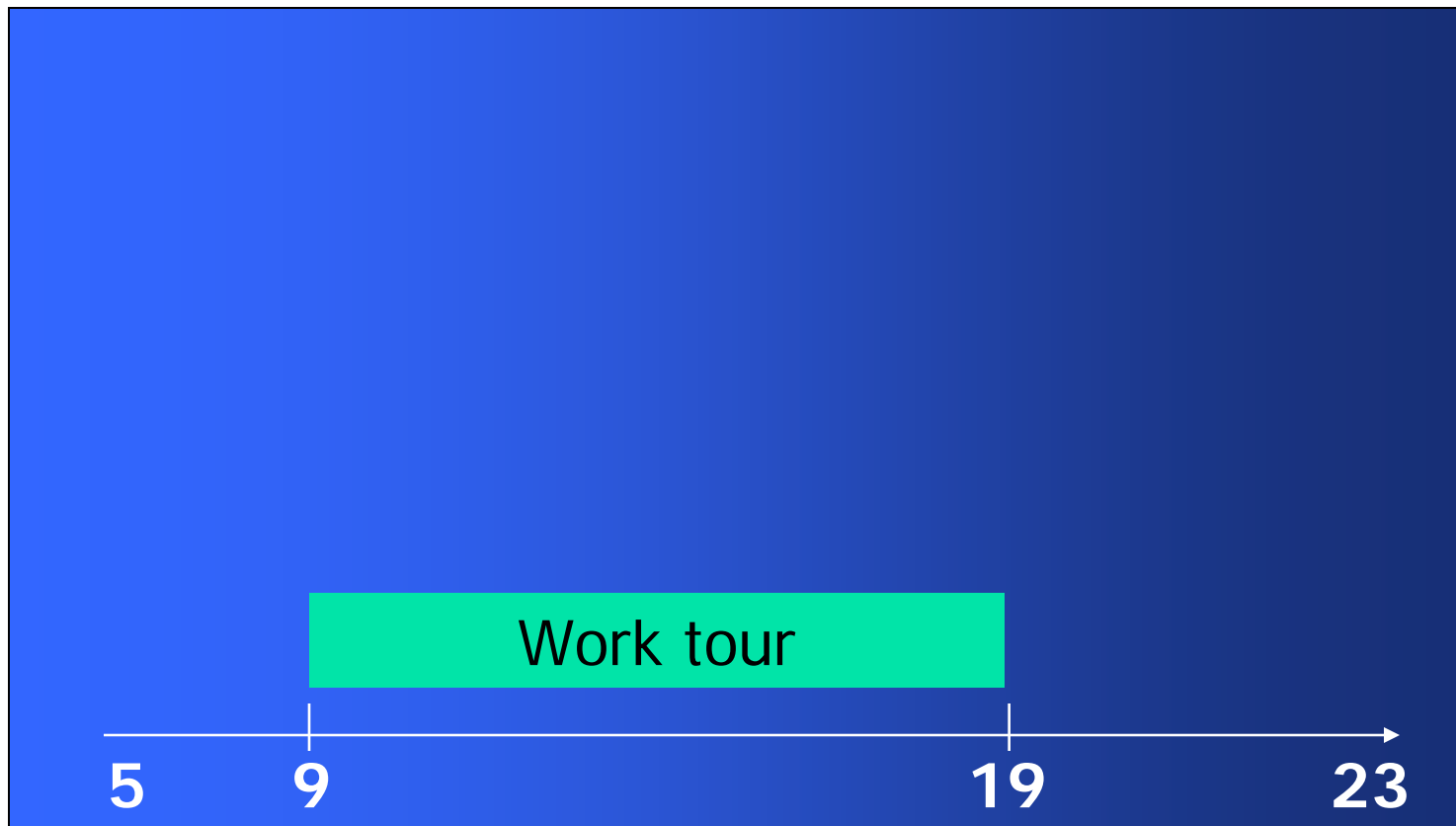
4-Step Model

- Focus on one period (AM peak)
- AM peak spreading isolated from other periods
- Sensitivity to pricing is overestimated:
    - Aggregation bias over VOT segments
    - Entire-day constraints ignored
- AM peak spreading can make PM congestion worse!
    - Shifting part-time workers to AM shoulder
    - Shifting non-work travel from AM period

Activity-Based Model

- Entire-day schedule
- AM Peak / PM peak spreading are modeled together
- Sensitivity to congestion pricing is realistic:
  - Various VOT segments
  - Entire-day constraints
- Impact of AM peak spreading on PM peak is modeled explicitly

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7. Toll Road as Travel Choice

Existing Approaches

- Assignment only (no demand changes)
- Binary choice (toll/non-toll):
  - Non-toll users diverted to other routes
  - Non-toll users diverted to other periods (peak spreading)
  - Non-toll users diverted from highway (diversion curves)
- Incorporation in mode / TOD / destination choice
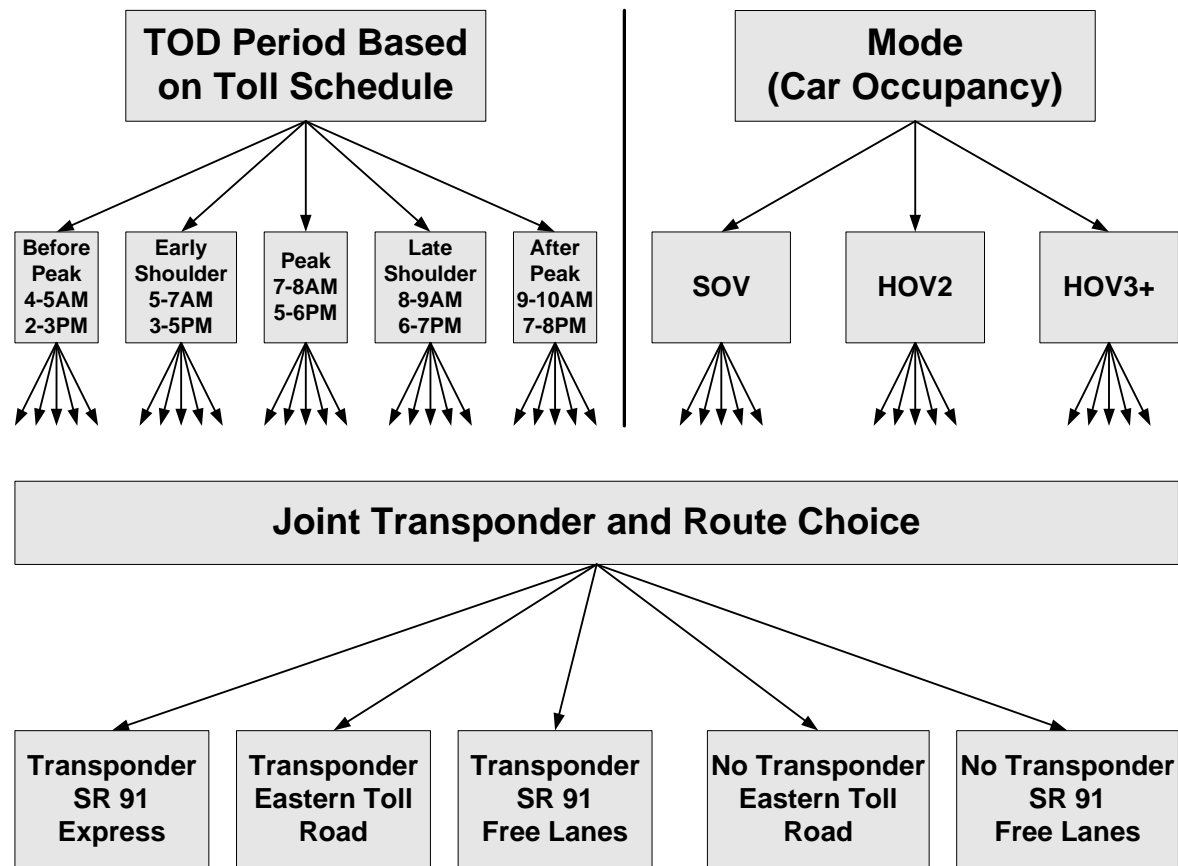
Mode & Toll Road Choice
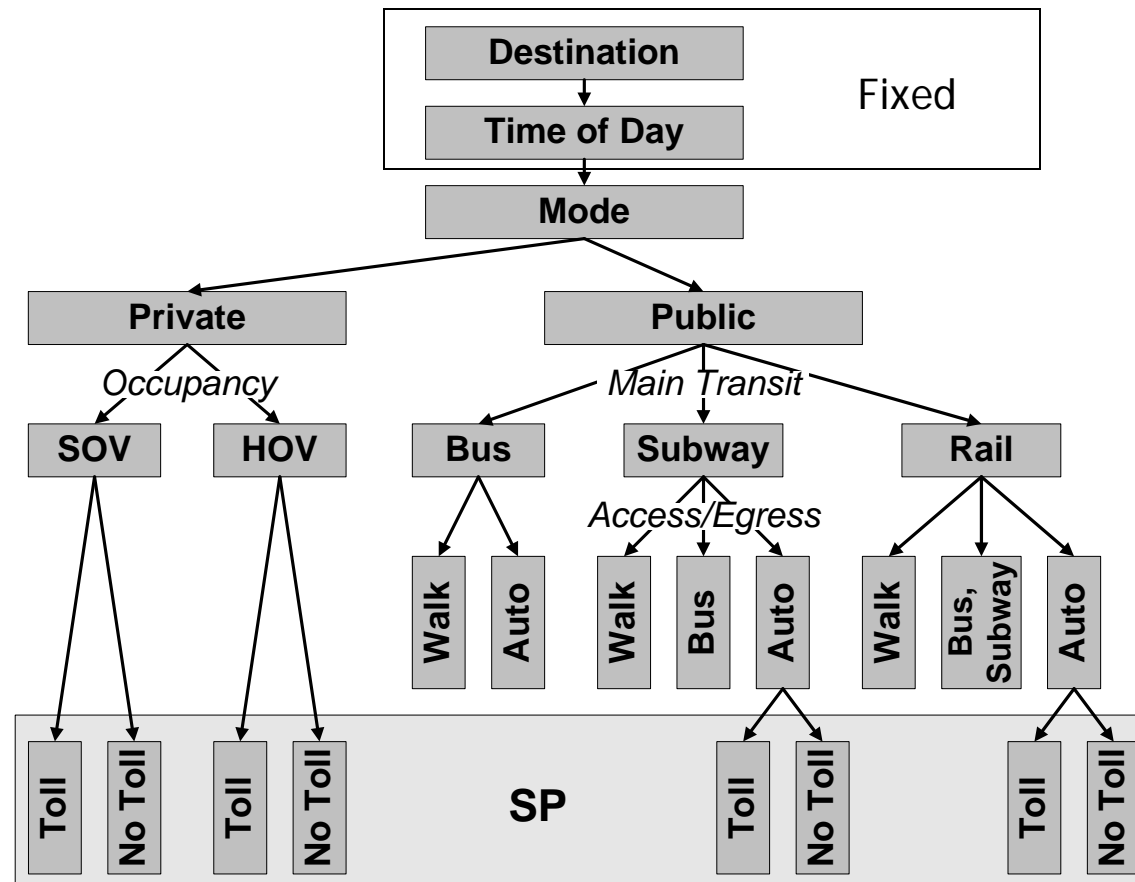
Additional Complications

- **Payment type choice (manual, EZ pass, transporder)**

- **Non-trip-based pricing forms (daily area pricing)**

- **Person-based exemptions / discounts / reimbursement**

- **Basic order of choices (mode, destination, TOD) is still an open issue**

SR-91 (Yan, et al, 2002)

TOD Period Based on Toll Schedule

- Before Peak 4-5AM 2-3PM
- Early Shoulder 5-7AM 3-5PM
- Peak 7-8AM 5-6PM
- Late Shoulder 8-9AM 6-7PM
- After Peak 9-10AM 7-8PM

Mode (Car Occupancy)

- SOV
- HOV2
- HOV3+

Joint Transponder and Route Choice

- Transponder SR 91 Express
- Transponder Eastern Toll Road
- Transponder SR 91 Free Lanes
- No Transponder Eastern Toll Road
- No Transponder SR 91 Free Lanes

Inclusion Recommendations

?	Trip generation	*Large-scale projects & policies*
?	Trip distribution	*Large-scale projects & policies*
☑	TOD choice	*TOD-specific pricing*
☑	Mode choice	*Strong transit alternative*
☑	Car occupancy	*Occupancy-specific pricing*
☑	Payment type	*Several technologies*
☑	Toll road choice	
☑	Network route	

Applied Combinations

? Trip generation

? Trip distribution

☑ TOD choice

☑ Mode choice

☑ Car occupancy

☑ Payment type

☑ Toll road choice

☑ Network route
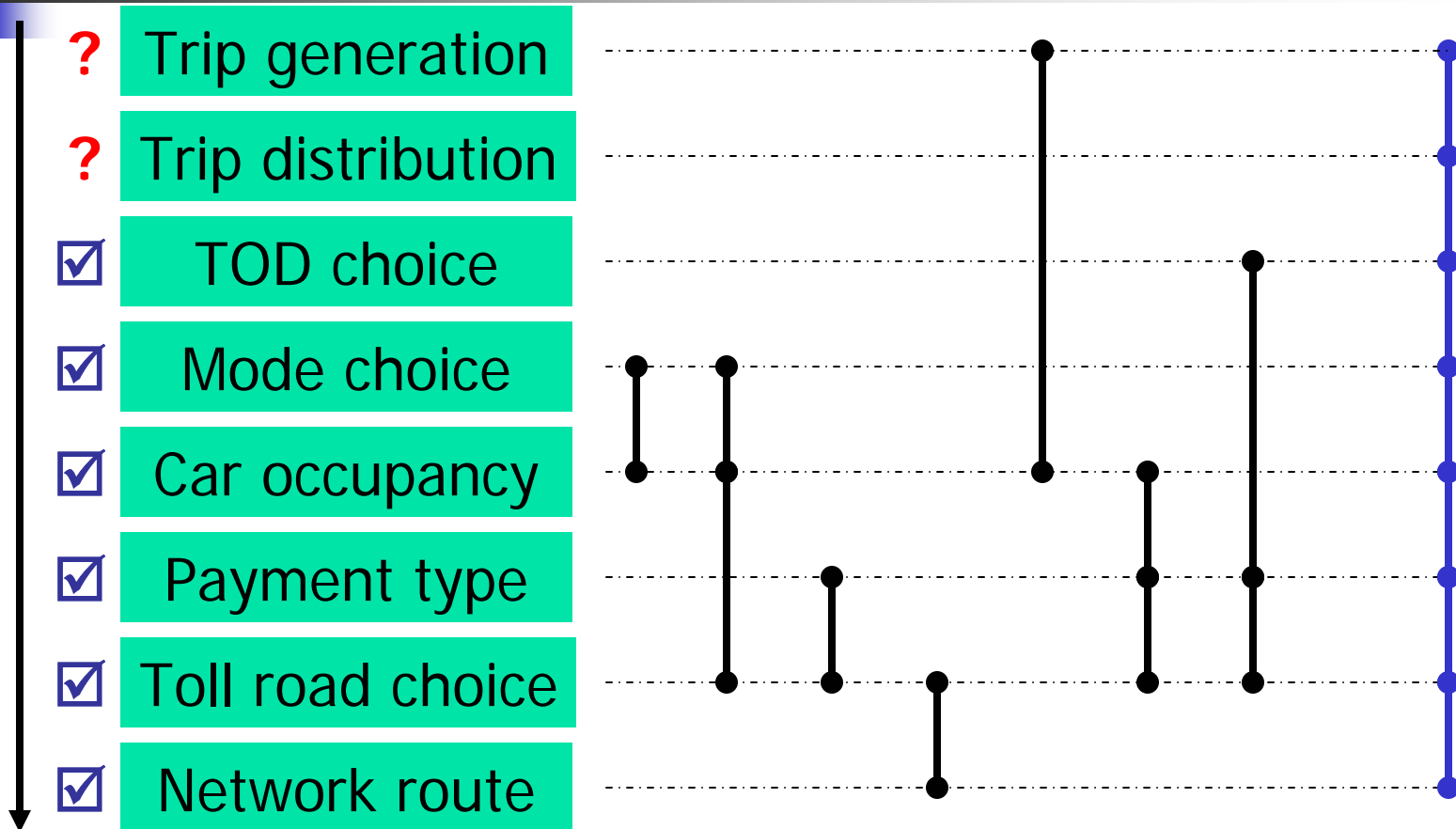
How many applied models address all aspects in a consistent way?
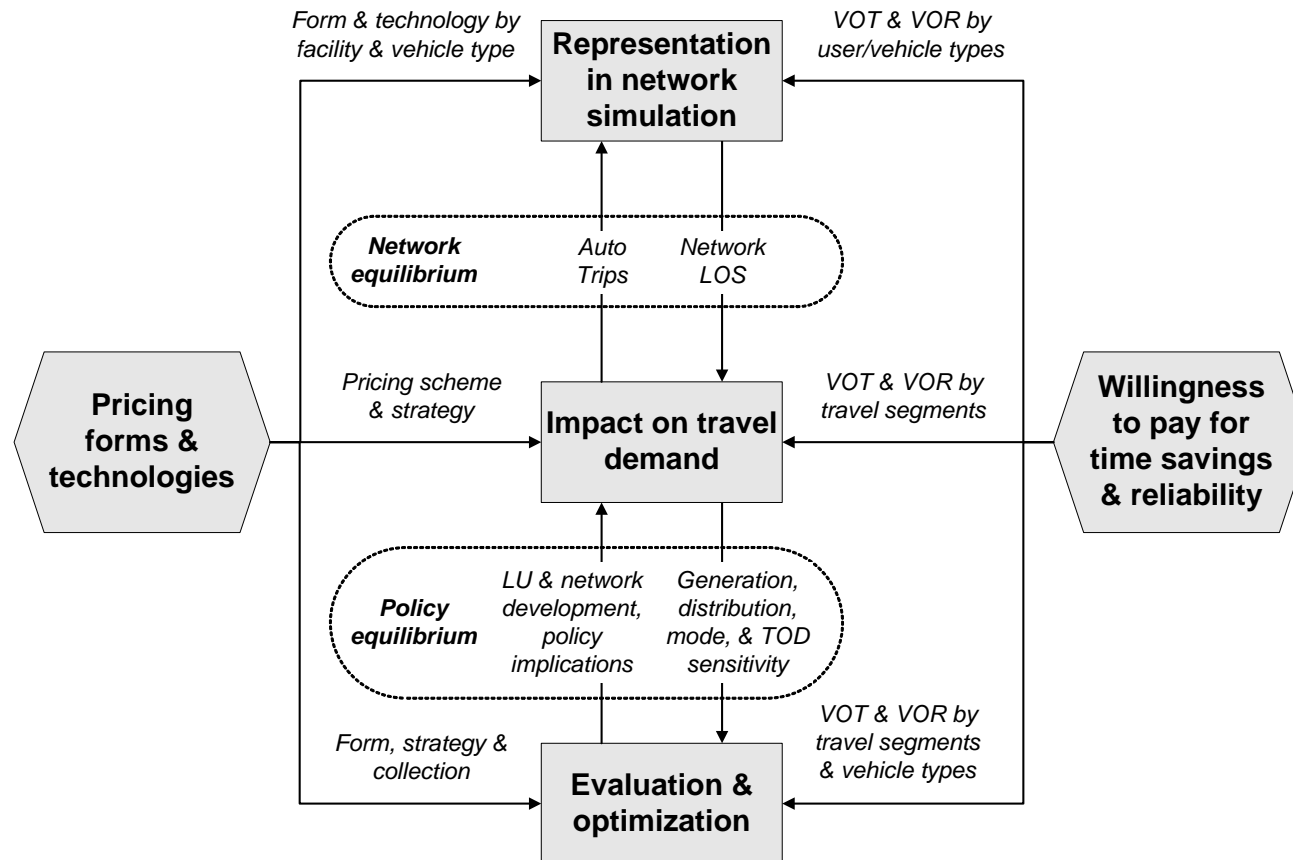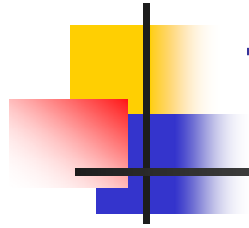
Conclusions

- **Right tool for the planning need and context:**
  - Available information / surveys
  - Existing modeling framework
  - Form / scale of pricing and expected impacts
- **Progress relates to general advances in modeling:**
  - Dynamic traffic assignment / micro-simulation
  - Activity-based demand models
  - Synthesis of good ideas & best practices
- **Integrated approach – "Bigger picture":**
  - Network simulation
  - Demand modeling
  - Evaluation / optimization

Integrated Decision Making

Thank You for Your Attention!

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